Broomrape-Halouk (*Orobanche* spp.) in the Sudan

Editors: Z. T. Dabrowski
and Abdalla Hamdoun

FAO/ARC Cooperative Project
Development and Application of Integrated
Pest Management in Vegetables, Wheat and Cotton,
Phase IV, GCP/SUD/025/NET, Wad Medani

Report on the First National Workshop on Control Methods of Broomrape, *Orobanche* in the Sudan

13 August 1995
Gezira Research Station,
Agricultural Research Centre

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The Food and Agriculture Organization of the United Nations

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Contents

Participants of the First National Workshop on Control Methods of Broomrape, *Orobanche* in the Sudan; 13 August 1995 at the Training Hall of the Integrated Pest Management Research and Training Centre, Gezira Research Station, Agricultural Research Corporation, Wad Medani.

Highlights of Discussions

A. Hamdoun and Z.T. Dabrowski

First National Workshop on Control Methods of Broomrape, *Orobanche* in the Sudan was jointly organized by the Agricultural Research Corporation, the Gezira University and the FAO/ARC Project on Integrated Pest Management on 13 August 1995 in the new IPM Research and Training Centre. The workshop has been sponsored by the Food and Agriculture Organization of the United Nations.

Forty-two representatives from four research stations of the Agricultural Research Corporation, the Gezira University, extension services of the Ministry of Agriculture, Gezira and Rahad Schemes and the international staff of the FAO IPM Project participated in the meeting. Most of the papers presented have reviewed available literature on *Orobanche* biology, ecology, physiology and control methods developed in the region. Some other papers have provided new information gathered on the broomrape economic importance, biology and potential control methods in the Sudan. Knowledge gaps and research activities to fill those gaps were thereby identified.

The participants noted with appreciation that three young researchers have undertaken Ph.D. and M.Sc. research projects on *Orobanche* with emphasis on integrated control measures as recommended by Dr Romero R. E. Labrada in his closing remarks at the end of the Regional Workshop on *Orobanche* and *Cuscuta* Parasitic Weed Management in the Near-East, Amman, 23–30 September 1993. Dr Labrada also noted that: "It was clear from country reports that training of research specialists and extensionists is one of the major requirements for success of any project in the region" (FAO, AGPP, 1994, p. 78), which was one of the objectives of our workshop in the Sudan.

The representatives of the extension services actively participated in the discussion on developing relevant and realistic recommendations to restrict spreading broomrape between fields in the affected areas in the Sudan and urged to prepare simple extension materials which should increase farmer awareness of the *Orobanche* threat to their crops; in many cases the income-generating crops such as tomato and other vegetables.

The workshop has endorsed establishing the *Orobanche* Working Group with the aim to integrate research activities presently conducted in three main institutions: Shambat Research Station (ARC), the FAO/ARC IPM Project at the Gezira Research Station (ARC) and the Gezira University (Wad Medani).

The participants acknowledged the usefulness of organizing the country conference on *Orobanche* and recommended to have regular annual workshops in different localities affected by broomrape. A field day will be organized by the FAO/ARC IPM Project jointly with the University of Gezira in Fadasi (recently heavily infested with broomrape) in February 1996 to review various control methods tested through participatory research with farmers.

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The Importance of *Orobanche* Parasitic Weed in the Sudan

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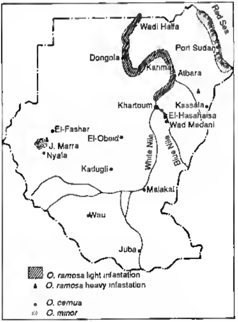
Orobanche — halouk, as the local name implies, is a devastating parasitic weed which parasitizes a range of dicotyledonous arable vegetable and ornamental crops in addition to several solanaceous weed species. In the 1950s Andrews made an impressive survey on the vegetation of the Sudan and reported three *Orobanche* species in the Northern States, Southern States, Darfur and Red Sea Hills. The three species were identified and described fully in Volume III of the *Flowering Plants of the Anglo-Egyptian Sudan* (1956).

Unlike *Striga* which parasitizes the staple food crops as sorghum and millet, *Orobanche* was considered a minor parasite infecting what were considered less important crops, i.e., vegetables and ornamentals. In the 1960s, however, vegetable production was expanded and intensive research started. New technologies were developed and intensified production for local consumption and export considerably increased. Unfortunately most of the production was restricted to the Nile banks in the Northern, Nile River, Khartoum and Gezira States. Solanaceous crops such as tomatoes, eggplants and potatoes were monocropped in these areas and as a result the *Orobanche* problem started to spread from north to south and infestation reached devastating levels in heavily infested soils. The continued production of tomatoes in Karima area to supply the tomato paste factory led to severe incidence of the parasitic weed, an eventual cessation of production, and closing down of the factory. In Fadasi (Gezira State), a field that was initially infested in 1988 and was continuously under tomato production is at present abandoned (Fig. 1).

It is, therefore, evident that the *Orobanche* problem is on the increase and should be considered the major problem facing production of the host vegetables in the Sudan. Despite this, the problem is still largely neglected. Research is limited and fragmented and is not considered a priority in the vegetable research programmes.

This First National Workshop on *Orobanche* in the Sudan which was planned, sponsored, prepared for and hosted by the FAO/ARC IPM project is a first step towards creating awareness among scientists, extensionists and crop protection personnel on the economic importance of the parasite in order to initiate problem-solving research programmes and advise on possible control measures from the limited available information. The

Fig. 1. Geographical distribution of broomrapes (*Orobanche* spp.) in the Sudan (after Babiker et al., 1993)



programme for the workshop has included information, presentations and discussions on biology and physiology, distribution and economic importance in the Sudan; investigations into the *Orobanche* problem in Khartoum State; critical evaluation of the control methods in the region, using neem leaf powder, a promising soil bio-herbicide for control; co-ordination of research in *Orobanche* in Sudan and developing extension materials for *Orobanche*.

The outcome of those presentations and discussions should without doubt lead to the compilation of considerable new information and pave the way for future research, better awareness of the problem and eventual integrated management.

We are grateful to the FAO/ARC IPM project for availing this opportunity to all of us to participate in this workshop. I am sure that presentations and discussions will be of interest and fruitful to all participants.

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Distribution and Economic Importance of *Orobanche ramosa* (Broomrape) in the Sudan

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Vegetable crops production has been widely extended in recent years as these crops gain special priority for export. But although production of vegetables has steadily increased, vertical productivity was poor due to invasion by numerous pests, including *Orobanche*, "halouk".

Orobanche ramosa L. is a serious root-parasite in the Sudan which attacks solanaceous crops, mainly during the winter season. Its damage to crops is sometimes so severe that complete crop failure can occur. Records collected from farmers' fields have shown that broomrape outbreaks started in 1980s in the Northern province mainly on tomato crops and the infestation later has spread along the Nile Valley and was associated with intensified agriculture (Babiker et al., 1993).

Broomrape was first noticed only on solanaceous crops but now it has a wide range of host plants such ss eggplant, cucurbits, squash, watermelon, faba beans, lentil etc.

Description of *Orobanche ramosa*

Orobanche ramosa is an annual root-parasitic plant with small branched stem with non-photosynthetic alternate leaves reduced to scales. inflorescence terminal, with many flowered spikes; parasite with a haustorium which absorbs soil nutrients and food substances from the host plant leading to complete yield losses. *Orobanche* parasitizes mainly solanaceous plsnts.

Distribution

In general *Orobanche* species are spread all over the world from Mediterranean region to United Kingdom, America, Africa and Asia.

In the Sudan, the *Orobanche* species have been recorded first in the Northern Region with highest infestation in the Nile Valley. *Orobanche ramosa* was reported as one of two major parasitic weeds in the Sudan (Babiker et al., 1993). In Khartoum State the damage is confined to winter season crops, mainly tomato and potato (Dongola, 1995). In El Geli 30% yield reduction was recorded on potato crops and

100% on tomato in 1994 and 1995. Infestation of tomato by *Orobanche* reached 40% at Shambat. It was also recorded on tomato and potato crops at Fakki Hashim, Karari, and Halfaya. In Saggay 30% yield reduction was observed on tomato crop. At El Ezergab the fields of tomato were highly infested by *Orobanche* and 70% yield reduction was recorded. "Halouk" invasion on eggplant reached 80% at Remela and 10% yield reduction on Gezira islang.

At Kamlin, infestation of vegetables by *Orobanche* was also recorded. At Gezira Umdagerssi, Fadasi and Amrab high infestation leading to 80% yield reduction in the tomato crop was observed.

Economic Importance

The agricultural sector plays the main role in the national economy. It is earning more than 80% GDP. The production of cotton as well as some vegetable crops is recommended as cash or export crops. The recent policy of the government is to encourage production and industrial utilization of some vegetables such as tomato and potato; but, unfortunately, the yield of these crops decreases drastically due to invasion of *Orobanche*, especially in most farmers' fields growing tomatoes. For example, in the Northern Province, the Karima factory for tomato paste was closed due to reduction of tomato yields.

Table 1 shows the production of potato at different agricultural sites which may be affected by the spread of *Orobanche ramosa*; moreover, this situation may lead to unemployment when these potato production sites are devastated by *Orobanche*. It is, therefore, highly recommended to initiate research work on this serious pest, as soon as possible, before the pest spreads in the country.

Table 1. Production of potatoes (t/ha) (after Elhassan 1989) potentially under threat by *Orobanche* (average of 4 seasons)

Hediba	19.83
Shehenab	20.95
Kassala	13.40
Shendi	17.60
Medani	4.6
Rahad	7.39
New Halfa	7.40

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Biology and Physiology of *Orobanche* spp.

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Broomrapes (halouk)—*Orobanche* spp. — which belong to the family Orobanchaceae are obligate parasitic flowering plants. They have been recognized as destructive root-parasites on solanaceous, leguminous and several other broad-leaf plants (Abu Shakra et al., 1970). The main area of distribution is the Mediterranean region and other regions with similar climate. Some species can be found in arid and semi-arid environments such as Sudan (Linke et al., 1989).

Three species of *Orobanche* were reported in Sudan by Andrews (1956) as localized agricultural pest: *Orobanche ramosa* L., *O. cernua* Loefl and *O. minor* Sm. These species were limited to the Northern and Khartoum states, but recent surveys show that the parasite has spread into the central and Kordofan states and is becoming a serious problem in certain localities. In Fadasi area (Gezira State) the first infested Gerif (Number 47/1) was detected by Dr Gasim A. Dafalla from the Gezira University in the 1988/89 season. At present this Gerif is no longer under cultivation because tomato was the main crop grown in this ares (Dafalla, personal communication).

Orobanche cernua Loefl. was reported in Darfur State on tobacco and also in the Eastern States. *Orobanche minor* Sm. was reported in Eastern and Equatoria States.

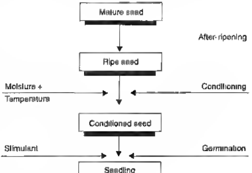
High crop losses by *Orobanche*, especially in hot dry areas, have been reported and crops were ploughed just after emergence.

Seeds

Seeds of *Orobanche* are microscopic, oval in shape, size varies according to the species and measure approx. 0.3 x 0.2 mm (Saghir, 1986). The seed weight ranges from 4–9 x 10^{-3} mg (Linke et al., 1989). A medium-sized *Orobanche ramosa* plant parasitizing potato roots produces about 400 flowers. Each flower produces between 500–700 seeds. Freshly harvested seeds remain dormant for several days or months depending on the species. Saghir (1986) believes that the seeds may need an after-ripening period of two years after which they remain viable in the soil for about 12 years. Results of our experiment in Sudan indicated that seeds of *O.ramosa* need an after-ripening period of only 2 months. Cezard (1973a) reported the presence of phenolic compounds in the seeds of 11

Orobanche species and these compounds may play a role in seed dormancy. Therefore, several preparatory metabolic processes take place before seed germination is possible (Fig. 1).

Fig. 1. Processes required for seed germination of a root-parasite (after Joel et al., 1994)



Seed Conditioning

A seed preconditioning period is very important in determining the percentage of germination. A moist environment is required for several days together with suitable temperatures to render the ripe seeds responsive to germination stimulants (Chabriolin, 1938; Brown and Edward, 1946). Vallance (1951) suggested that conditioning is necessary to increase the permeability of the seed coat to water and gases and attain the critical level of required factors or biochemical stages which are needed for the germination stimulant to be effective.

Conditioning time increases the sensitivity to germination stimulant. Optimum temperature and period of conditioning vary from one species to another and even between different seed population (Joel et al., 1994). In general eight days are required at the temperature of 25°C to produce the highest germination in *O. ramosa* in Sudan (Table 1). The effect of light on germination of *Orobanche* species was species dependent. Germination of *O. ramosa* seemed to be indifferent to light, whereas germination of *O. aegyptiaca* was completely inhibited by light (Borg, 1986). The addition of germination stimulants to the conditioning medium inhibited *Orobanche* germination (Hsiao et al., 1981).

Germination Stimulanta

In all psrasitic flowering plants germination starts only when host plant roots are avsilable in the immediate vicinity of the parasite seeds (Joel et al., 1994). Although most species germinate only in the presence of s stimulant from the host, some spontaneous germinstion has been reported in *O. ramosa* (Garman, 1903; Duria, unpublished).

The chemical structure of *Orobanche* stimulants has not been determined but some evidence suggests that it may be a benzopyran derivative (Davis et al., 1977 and 1978). Musselman (1980) indicated thst information about compounds that stimulate germination of *Orobanche* is limited. However, strigol and strigol analogues sffect germination.

Strigol is the first germination stimulant isolated for *Striga* (Cook et al., 1966, 1972). It is an extremely potent germination stimulsnt of many root parasites exhibiting activity at concentration as low as 10^{-6} M (Worsham, 1987). Saghir (1986) indicated thst strigol analogues (GR_7, GR_{24}, GR_{28}, GR_{41}, GR_{45}, and GR_{53}) were sctive in stimulating *Orobanche* germination at concentration ranging from 0.1–10 ppm. On the other hand, the fore-mentioned compounds tended to inhibit germination at concentrations higher than their respective optimal.

Although *Orobanche* species showed a strong positive response to strigol and related compounds, a moderate response (50–75% germination) to gibberellic acid, pyridoxine and nicotinamide was evident, but the response to kinetin, auxin and other compounds was low (Foy et al., 1989). Ethylene failed to stimulate germination of *O. crenata* (Edwards et al., 1976). Jackson and Parker (1991) and Logan and Steward (1992) provided evidence for the involvement of ethylene in germination induced by host root exudates.

Host Plant-Parasite Relations

One of the possible reasons for specificity of the various parasitic plant species for a particular host species might be a differential germination response of the parasite to the potential host root exudates. Such differential germination stimulant response matching the specificity of the parasitic interaction has been reported at both the species and the cultivar/race level (Joel et al., 1994). The most striking host specificity is evident in *O. cumana* which is attacking only sunflower and few related Compositae (Joel and Jacobsohn, 1988). Germination of this species is more sensitive to sunflower exudate than that of flax which is a catch crop. This difference seemed to be entirely due to differential stimulation without any significant inhibitory effects at the relevant concentration (Mathews et al., 1991). Strain specificity was simply explained on the

basis of differential germination (Parker and Reid, 1979).

The adverse effect of the parasite on the host is both direct and indirect. Water and nutrients are removed from the host plant and stunting and yield reduction occur (Cezard, 1974 and Cordas, 1973). The movement of photosynthates from host to parasite is well documented (Okonkwo, 1966; and Saghir, 1986). In essence the parasite becomes a metabolic sink for carbohydrate produced in the host (Lee and Goseco, 1932). Munteanu (1972) found that the host plant contained more starch and non-reducing sugars than the parasite. Parasitism by *Orobanche* also reduces the level of nucleoprotein in the host stem but not in the root (Singh, 1971) as well as lowering the chlorophyll content (Singh and Krishnan, 1971). Press et al. (1986) and Wegman (1986) indicated that high concentration of mannitol in *Orobanche* has been implicated in the generation of an osmotic gradient between host and parasite. Osmotic pressure in the host is reduced to an extent that symptoms like wilting and drought stress can occur (Linke et al., 1989).

Haustorium Development

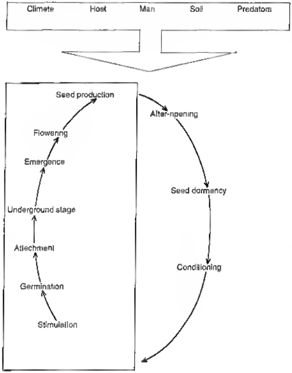
The haustorium is in fact the salient feature of parasitic weeds because through it all transfers between host and parasite are achieved (Musselman, 1980). Upon germination a hyaline, root-like structure (germ tube) expands out of the testa. The germ tube can reach a length of 3–4 mm with a diameter of 0.15 mm. For this reason only seeds in the immediate vicinity of host roots (3–4 mm) can parasitize the host (Linke et al., 1989). This developmental stage is known as apresorium. The apresorium connects itself to the host root following enzymatic degradation and mechanical penetration into the host root vessels.

The connecting tissue is the haustorium. As soon as the first cell reaches the vessels they differentiate into xylem element establishing a direct connection. The outer part of the haustorium gives rise to a tubercle which develops into a single shoot apex and many short roots (Aber, 1984). Crown roots develop on the tubercle and then a bud develops which later forms a shoot.

While *Orobanche* is in the underground developmental stages it accumulates carbohydrate with limited visible growth. Carbohydrate reserve enables the parasite to elongate its shoot, emerge from the ground and **flower within a very short period** (1–2 weeks under Sudan conditions).

Duration of shoot development and emergence is closely related to soil, temperature, and the nutritional status of parasite and crop. The underground developmental phase ranges from 30–100 days while the whole life cycle ranges from 3–7 months (Linke et al., 1989) (Fig. 2).

Fig. 2. The life cycle of *Orobanche* spp. (after Linke et al., 1989)



Effects of Environmental Factors on *Orobanche* - Host Relationships

Orobanche flourishes in an open sunny habitat and relatively poor soils. Environmental factors influence the size of the root system either directly by affecting absolute growth or indirectly by affecting root/shoot ratio. In general, a low level of mineral and water leads to a high root/shoot ratio whereas this ratio is relatively low at low light intensities. The ecological significance of a negative effect of light is obvious (Borg, 1986). Racovitza (1959) indicated that the daily fluctuation of temperature

increases germination of *O. ramosa*. Variations also exist at the intraspecific level. The optimum temperature for *O. ramosa* germination is 18°C in USA, 20°C in South Germany and 25°C in Lebanon (Borg, 1986).

The *Orobanche* problem is generally less expressed in moist soils. Waterlogging has an indirect effect on reducing oxygen supply which keeps the seeds dormant or hinders attachment and seedling establishment (Borg, 1986).

Generally manure and fertilizer reduce the *Orobanche* problem and increase crop yield. According to Bischoff and Koch (1973) the yield increase is caused by a reduction in the number of *Orobanche* spikes. Germination is maximum in slightly acid soil probably due to an interaction with the germination stimulant (Saghir, 1986).

The presence of bacteria is necessary for the germination of several *Orobanche* species. *Rhizobium* species seem to be essential for *Orobanche* attack on *Vicia faba* as they help in penetration (Cezard, 1973b). Furthermore there is a relation between resistance against *Orobanche* and resistance against various fungi (Vranceanu et al., 1986).

Some Aspects of the *Orobanche* Biology in the Sudan

The presented study has been conducted as part of a Ph.D. programme on the Biology and Control of *Orobanche ramosa* L., on Solanaceous Crops in Sudan. The laboratory experiments were conducted at the University of Nantes, Faculty of Science and Technology, France. The objectives of these experiments were to study the effects of natural and artificial stimulants on *in vitro* germination of *Orobanche* and determine the optimum preconditioning period.

Seeds of *Orobanche* were collected in the 1994 season from different hosts (tomato, potato, eggplant, *Datura*, *Solanum dubium*, faba bean, carrot and banax) grown in different areas in the Sudan: Fadasi, Umilella, Karari, Shambat and Elgaili locations.

Seeds of *Orobanche* were surface sterilized by 0.5% sodium hypochlorite for 5 minutes. The preconditioning was carried out on 8-mm glass fibre filter paper discs in 9-cm sterile Petri-dishes. The preconditioning periods have ranged from 7–15 days at 25°C in the dark. Then the discs were transferred into other sterile Petri-dishes which had filter papers saturated with GR_{24} stimulant at concentrations of 0.1 and 10 ppm. Then the treated Petri-dishes were incubated at 25°C for 12 days in the dark; after which discs were examined under a binocular microscope and germination percentage of seeds was determined.

In another experiment, three natural exudates from various tomato cultivars (Person, Peto 86 and Strain B) were used. The exudates were prepared by placing a number of different seedlings (between 2 to 4

weeks age) in small beakers containing 25 ml of sterilized distilled water. These were then incubated at 25°C under different exposure to light and for different periods. Then the exudates were filtered using Analpore filter in sterilized test tubes.

Table 1 shows that all the seeds of *Orobanche* collected from Sudan have been stimulated by GR_{24} at the different concentrations. GR_{24} at 0.1 ppm showed the higher stimulstion which rated from 58.3–100% germination, 1 ppm stimulation rated from 44.0–94.5% and 10 ppm from 36.4–100%. This proved the fact reported by Saghir (1986) who indicated that GR_{24} at 0.1–10 ppm caused significant increases in the stimulation of *O. ramosa*. Germination percentage increases with the decrease of the preconditioning period, as we found that 8 days seems to be required for preconditioning for highest germination of *O. ramosa* (Table 2). Tables 1 and 2 indicate that *Orobanche* collected from potato, *S. dubium* and banax showed a spontaneous germination in the absence of GR_{24}. This proved the observations of Garman (1903) who reported the presence of spontaneous germination in *O. ramosa*. Further

Table 1. The effect of artificial stimulant GR_{24} on germination of *Orobanche* collected from various crops and locations in Sudan

Host	Area	Precon days	% of Germination			
			0.1 ppm	1 ppm	10 ppm	Control
Potato	Kareri	8	86.7	94 5	92.4	18 8
Eggplant	Shambat	8	88 6	54.5	52 9	0
Datura	Shambat	8	58.3	41 6	36.4	0
S. dubium	Shambat	11	100	87.5	100	0
Banax	Shambat	11	94.1	94 1	95	25
Tomato	Shambat	8	92 4	90.5	87 3	19
Broad-bean	Shambat	9	85	90	88.1	0
Tomato	Umlella	8	2.7	5	10.9	0
Carrot	Eligeili	8	67.1	57.7	66.2	0
Tomato	Fadasi	8	62 3	44.0	69 3	0

experiments, however, indicated that there are many other factors involved in the recovery of root exudate from the host (Table 3). These factors are as follows: the stage of growth at the time of exudate collection; the incubation period and exposure period to light. Between the three tested cultivars only exudates from Strain B (3 weeks old) at low concentrations were effective in stimulating the germination of *O. ramosa*. This may be explained by previous reports by Whitney (1979) who indicated that

material exuded by host root stimulates broomrape seed to germinate but higher concentration of exudate inhibits the germination.

Table 2. The effect of preconditioning period on the percentage of *Orobanche* germination using GR_{24} as germination stimulant

Host	Area	Precon, days	% of Germination			
			0.1 ppm	1 ppm	10 ppm	Control
Tomato	Fadasi	15	5.6	4.6	22.4	0
	Fadasi	12	41.7	25.8	34.9	0
	Fadasi	8	62.3	44.0	69 3	0
	Fadasi	7	60.1	22.3	43.8	0
Potato	Karari	12	13.9	26.6	21.7	0
	Karari	10	85 4	96 3	94.6	3.1
	Karari	8	94.4	95.0	90.2	20
	Karari	8	93.9	92.0	81.0	0

Table 3. The effect of natural exudates on *Orobanche* germination

Cultivar	Age	No. of seedlings/beaker	Incubation period	% of Germination			
				1st	2nd	3rd	4th
Peto 86	4/wk	6, 9, 18, 36	1 day/D	0.9	0.5	2.4	2.4
	3/wk	6, 9, 18, 36	1day/D	0.9	1.0	6.6	29
	2/wk	`6, 9, 18, 36	2 days/D	2.2	2.1	3.5	6.1
	2/wk	6, 9, 12, 15	2 days/D & L	35.2	4.8	6.3	6.1
Person	4/wk	3, 6, 9, 16	1 day/D	13.0	25.1	4.5	0.8
St. B.	2/wk	6, 9, 16, 36	2 days/D & L	2.8	1.9	1.7	2.3
	3/wk	6, 9, 12, 16	3 days/L	55.9	65	75.5	52.9
				62.3	65	78.2	59.8

wk = weeks; L = light; D = dark; St. B. = Strain B;
1st, 2nd, 3rd and 4th concentrations according to the number of seedlings/beaker.

Conclusion

The results presented above indicate that there is an inhibition of seed germination from the host plant. More investigations are needed to select the host plant varieties that produce high levels of inhibitor and low level of stimulant, and on cultural conditions that are

inducing similar effects, which might significantly reduce the level of infestation in the field as suggested by Whitney (1979).

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Broomrape, *Orobanche ramosa*, in Khartoum State

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Broomrape, *Orobanche* spp., is a parasitic weed which affects the growth of many important broad-leaf crops in different areas of the world. The severe infestation of *Orobanche ramosa* L. has been reported in the major vegetable producing areas of the Sudan particularly in Khartoum State. The yield losses ranged between 80–100% of tomato, potato and eggplant which are the most important crops in Khartoum State (Ismail, 1979 and Babiker et al., 1993). On the other hand, the Canning Factory in Karima was closed due to abandoning of tomato production.

However, the information on distribution of broomrapes in the Sudan is limited and control methods are restricted to hand weeding and abandonment of susceptible crops (Braun et al., 1985; Babiker et al., 1993). Soil solarization was reported to be the most suitable method under Near-East conditions; but it is limited due to the high expenses and not adopted on a large scale (Braun et al., 1985 and Garcia-Torres, 1993).

The objectives of our studies were as follows:

(i) highlighting that *Orobanche* may be the most important weed in the vegetable production areas in Khartoum State;
(ii) providing quantitative data on its distribution;
(iii) studying the effect of pre-sowing irrigation, and transplantation versus direct sowing on *Orobanche* infestation on bost plants.

Materials and Methods

The survey was carried out on four crops grown on several fields in seven villages in Khartoum State in 1994. The sample unit was 5 x 5 m plot and replicated four times making a total of 100 m² sampled in each field. Five fields of either tomato, potato, eggplant and faba bean were selected at random in each village. *Orobanche* shoots in the quadrant were uprooted, counted and recorded. Mean of density of *Orobanche* was computed (Carson, 1988).

The studies on the effect of pre-sowing irrigation were conducted in the glass-house under approx. 22.8°C at the University of Khartoum, Faculty of Agriculture. Pots, 25 cm in diameter, containing approximately 10 kg of loamy soil were infested with 15 mg of broomrape seeds. The infested pots were irrigated at 45, 30, 21 and 14 days and 0 days before transplanting the tomato seedlings. The control treatment was only irrigated after transplantation of seedlings (as other treatments).

Five-weeks-old tomato seedlings, Strain B cultivar, were transplanted into the treated pot (two plants per pot). The pots were surface irrigated with water and arranged in complete randomized design with four replicates.

In addition, visual observations were carried out in three fields sown in the Garif land in Karari after the natural flooding of the Nile as follows:

1. Sown in flat plots after flooding without irrigation.
2. Sown in flat plots after flooding and irrigation.
3. Ploughed and ridged after flooding and sown with tomato and irrigated regularly.

The following methods of investigating the direct versus transplanting were used: five seeds of tomato variety, Strain B, were sown in the above-mentioned infested pots. After germination, the seedlings were thinned to two plants per pot in the direct seed treatment. On the other hand, 5-weeks-old tomato seedlings were transplanted into the infested pots (two plants per pot). This experiment was designed in a complete randomized design with three replicates.

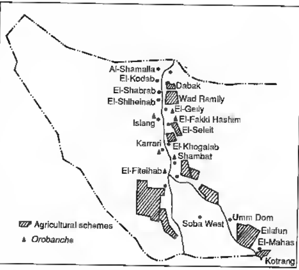
Results and Discussion

Survey

All fields surveyed were infected with *Orobanche ramosa* and the infestation levels at El-Geily and El-Neia were 100% on tomato and eggplant followed by faba bean (76.7%) and potato (34.6%) (Tables 1, 2; Fig. 1). in other villages surveyed, the infestation ranged between 8.1–40.0%. Besides these crops, other infestations were observed on carrot and cucurbitaceae crops in El-Geily location (Fig. 1).

These villages are considered to be major vegetables producing areas in Khartoum State. According to Carson (1988) 1–5 shoots of *Striga* caused 10% yield losses of sorghum in Gambia and our observations may indicate that *Orobanche* infestation caused several losses of the most important crops in Khartoum State. Host plants identified by us in the Khartoum State are listed in Table 3. However, more detailed studies are needed on

Fig. 1. Location of agricultural schemes and *Orobanche* appearence on vegetable crops in Khartoum state



mapping of infested areas and determining the percentage of yield losses in addition to percentage of infected crop plants.

Effect of Cultural Practices

Pre-sowing irrigations reduced the incidence and dry weight of broomrape shoots compared with control in the potted experiment (Fig. 2). Results of the observations on the natural flooded fields near the Nile confirmed clear differences of *Orobanche* infestations depending on flooding and irrigation. The severe infestation was shown in the field ploughed, sown with tomato and irrigated, and less infestation was shown in the flat and irrigated field. These results are in general agreement with those

Table 1. Percentage of infested host plants/100 m² by *Orobanche*; the 1993/94 growing season

Area	Tomato	Potato	Eggplant	Faba bean
Dabbak	39.7	-	0	-
Wad Ramily	42.4	-	-	-
El-Gelly	100.0	34.6	-	76.7
El-Neia	-	6.2	100	19.4
El-Sagal	40.0	36.3	-	10.0

Table 2. Density of *Orobanche* on various host plants in different areas of the West Nile, 1994 (No. of shoots per m²)

Area	Tomato	Potato	Eggplant	Faba bean
Dabbak	1.467	-	-	-
Wad Ramily	12.018	-	-	-
El-Gelly	101.050	1.93	-	5.43
El-Neia	-	0.73	38.225	1.05
El-Sagal	4.153	1.30	-	1.93

Table 3. Host plants of *O. ramosa* reported in the Sudan

Family	Crop	Common weed
Solanaceae	tomato, eggplant, bell pepper, potato and tobacco	*Datura stramonium* *Solanum dubium*
Fabaceae	pea, chickpea, faba bean	
Cucurbitaceae	squash, cucumber	

carried out in the pot experiment, particularly when sown flat and irrigated.

Several studies and observations have been mentioned to explain the effect of flooding and pre-sowing irrigation on broomrape infestation worldwide. The results are in agreement with suggestions that the seeds of *Orobanche* lose their viability after one month storage in water. This may be temporary dormancy because when ploughed and irrigated after natural flooding, high infestation was observed.

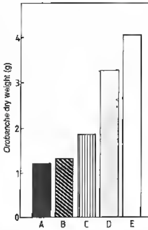


Figure 2. Effect of pre-sowing irrigation on the dry weight of *Orobanche* growing on tomato plants: treatment irrigated at the following day before transplanting tomato seedlings;

A - at 45 days, B - at 30 days,
C - at 21 days, D - at 14 days,
E - Control (no pre-sowing irrigation)

A good suppression of *Orobanche* was observed when tobacco and faba bean were rotated with flooded rice crops and tomato grown in two months flooded field (Zahran, 1982; ter Borg and van Ast, 1991; Parker and Riches, 1993).

On the other hand, ter Borg and van Ast (1991) showed that *O. crenata* numbers and dry weight could be increased under wetter conditions because the soil moisture affects host root system which influences broomrape numbers.

Direct sowing reduced the incidence and dry weight of *Orobanche* shoots compared with the transplanting method (Table 4). Zahran (1982) found that direct sowing was superior to transplanting, increasing crop tolerance to *Orobanche* attack.

Table 4. The effect of transplanting versus direct sowing on *Orobanche* incidence and weight

Method of sowing	Mean no. of *Orobanche*/wk after planting					Fresh weight of *Orobanche* shoot(mg)	Dry weight of *Orobanche* shoot(mg)
	6	7	8	9	10		
Trans-planting	1.33	7.67	15.33	20.0	25.0	22.167	3.330
Direct seeding	3.33	7.00	12.33	14.0	16.0	16.030	1.967

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Critical Evaluation of Control Methods of *Orobanche* Parasitic Weed in the Region

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To understand the effect of several methods of *Orobanche* control it is necessary to mention some critical biological and ecological characteristics affecting broomrape distribution, development and seed dormancy in the soil which makes its eradication mostly impractical in any country in which the parasite is widely spread.

Biological and Ecological Factors Affecting Broomrape Control

Orobanche species can parasitize many different wild plant species (including weeds) in addition to cultivated crops (Table 1). We are therefore, not surprised to find new occurrences of these species in different parts of the world.

The second factor is the great reproductive potential of *Orobanche* species. Their seeds can only be seen under the microscope (0.3 x 0.2 mm) and are produced in large numbers. About 500–5000 seeds are produced per capsule and 5000–20,000 seeds per plant (Saghir, 1986). The seed coat shows characteristic thickening at the surface which helps in dispersal by wind and water. The seed may need a period of two years for after-ripening to occur, after which it can remain viable in soil for at least 12 years (Saghir, 1986). The seeds germinate only in the presence of stimulants exuded by roots of host plants or some non-host plants which are not parasitized (such as flax for *Orobanche ramosa*).

Temperatures of 20–25°C are optimal for germination of broomrape seeds, with 8°C as the lower limit and about 30°C as the upper range (Kasasian, 1973). Germination increases with daily fluctuations of temperature for *O. ramosa* (Racovitza, 1959). *Orobanche* seeds must pass through some lower temperatures in order to germinate. This is why *O. ramosa* is a problem in winter crops in the Nile Valley but does not attack the same crops if grown during the summer (Musselman, 1986). Jacobsohn et al. (1980) used the effect of high temperatures as a means of control. Solar heating of soils covered with plastic sheets raises temperatures to about 50°C and this is high enough to kill the seeds (on mulched soil temperature is around 40°C and *Orobanche* seeds remain viable).

Table 1. Main crop hosts of *O. ramosa/aegyptiaca* (after Braun et al., 1984; Parker, 1986 and Babiker et al., 1993)

Family	Species
Solanaceae	Tomato (*Lycopersicon esculentum* Mill.) Eggplant (*Solanum melongena* L.) Bell pepper (*Capsicum frutescens* L.) Potato (*Solanum tuberosum* L.) Tobacco (*Nicotiana tabacum* L.) *Datura stramonium* L., *Solanum dubium* Fresen., *Solanum nigrum* L.
Leguminosae	Faba bean (*Vicia faba* L.) Lentil (*Lens culinaris* Medic) Chickpea (*Cicer arietinum* L.) Pea (*Pisum sativum* L.) Phillipsara (*Vigna trilobata* L.)
Cucurbitaceae	Squash (*Cucurbita pepo* L.) Cucumber (*Cucumis sativus* L.) Musk melon (*Cucumis melo* L.) Water melon (*Citrullus lanatus* (Thumb.) Mansf.)
Cruciferae	Rape seed (*Brassica napus* L.) Mustard (*B. juncea* L.) Cabbage (*B. oleracea* L.)
Compositae	Lettuce (*Lactuca sativa* L.) Sunflower (*Helianthus annuus* L.)
Umbelliferae	Carrot (*Daucus carota* L.) Celery (*Apium graveolens* L.) Fennel (*Foeniculum vulgare* Mill.) Parsnip (*Pastinaca sativa* L.)
Cannabidaceae	Hemp (*Cannabis sativa* L.)
Malvaceae	Mallow (*Malva parviflora* L.)
Euphorbiaceae	*Chrozophora plicata* (Vahl) A. Juss ex Spreng.
Libiatae	Sweet basil (*Ocimum basilicum* L.)
Tiliaceae	*Corchorus olitorius* L.
Aristolochiaceae	*Aristolochia bracteolata* Lam

The other factor affecting control of *Orobanche* is the easy distribution of seeds between fields by irrigation water, wind, on agricultural machines and by farm animals. Jacobsohn et al. (1985) has demonstrated that broomrape seed could pass through the digestive tract of sheep without losing viability, at least partially. Broomrape seeds may spread over long

distances with crop seed and planting materials. It was suggested that branched broomrape (*O. ramosa*) was introduced into the USA in the 1930s from overseas with imported crop seeds.

Mesa-Garcia et al. (1986) observed in his field studies in Spain that the number of broomrape, *Orobanche crenata* plants has increased progressively over the study period from 38 to 958 and 2949 per 2500 m^2 plot in 1983/84 and 1984/85, respectively, indicating a 25-fold rate of increase in the number of broomrape plants between the first and the second year of the study.

Orobanche is reported to be more detrimental to the crop on soils of low fertility. Improving the soil fertility appears to decrease infestation. Generally it can be stated that manure and fertilizers reduce *Orobanche* problems and increase crop yield; it is farmers experience, tested already in the first half of the 19th century. It has been shown by various authors that the weight and numbers of *Orobanche* decreased when fertilizers were applied, and crop yield increased (Southwood, 1971; Bischoff and Koch, 1973; Abu-Irmaileh, 1979, 1982; Kukula and Masri 1984). The most positive effects were obtained with balanced levels of N, P and K, but these minerals have also positive effects when applied separately since they influence hormonal systems (Abu-Irmaileh, 1979, 1981; Knutson, 1979; Ernst, 1986). Ernst (1986) believed that the beneficial effect of fertilizer with ammonia may be the result of its direct interaction with the metabolism of broomrape. An increased ammonium supply generally reduces the uptake of potassium and may affect the osmotic balance of broomrape. Ammonia used as $(NH_4)_2SO_4$ and urea *in vitro* had a negative effect on the germination percentage and on the growth of the procaulome of *Orobanche crenata*, but nitrate $NaNO_3$ had no such effect. However, the effect was not reproduced when the experiment was repeated under soil conditions (ter Borg, 1986).

The main dispersal of broomrape follows the row direction, possibly due to the influence of tillage and harvesting (Mesa-Garcia et al., 1986). Root density of the host plant which stimulates broomrape germination and emergence is higher along rows, due to the geometry of the plantation. The wind seems to play a secondary role only in seed dispersal. However wind may be deviated along row direction too.

Infested water reservoirs may be a source of broomrape seed dispersal where sprinkler irrigation, farrow irrigation or flooding irrigation is practised. However, the seeds will not pass through the filtering systems used for drip irrigation (Jacobsohn, 1986).

Status of *Orobanche* Control in the Region

A recent workshop on *Orobanche* and *Cuscuta* Parasitic Weed Management in the Near East organized by the Plant Protection Service of the Food and Agriculture Organization of the United Nations in 1993

in Amman, Jordan (FAO, 1994) revealed a number of constraints in the efficient control of *Orobanche*. Most countries in the region suffer from *Cuscuta* and *Orobanche* (both parasitic weeds) which are spreading fast because they remain unchecked. Farmers control these parasitic weeds by hand pulling or neglect control, due to shortage of facilities, or due to the non-profitability of control (i.e. no yield increase and/or no return). Control measures are normally carried out late, at flowering and seed setting, after the damage has taken place.

Most farmers plant locally produced seeds which are often contaminated with the parasite seeds. In many countries, contaminated crop seeds cross the borders unchecked at the quarantine centres, which are short of well-trained personnel for identifying the problem. Also, tolerance of parasitic weeds presence in imported commodities has not been established.

Most farmers spread unfermented contaminated manure for fertilization. Animals grazing infested fields move freely to non-infested areas. The same is true with tillage and harvest equipment. Infested hay or feed are not destroyed, but fed to non-grazing animals and their manure is sold to other farmers for fertilization.

Farmers are unaware of the reproduction means of parasitic weeds and accordingly they lack the proper phytosanitary measures. Hand-pulled broomrape plants are randomly thrown around the fields and infested borders remain unchecked. Officials are not aware of the magnitude of the parasitic weeds problem for lack of field surveys, and for prioritizing other input measures such as improved tillage, higher yielding varieties, irrigation and fertilization, all of which can be of little benefit under the threat of broomrape infestations.

Extension and research facilities are commonly under-staffed with subject matter specialists, resulting in very limited work accomplished, if any. Extension services in parasitic weeds is also lacking in most cases. Moreover, extension agents in many countries are secondary school graduates, if not less. The link between research and extension has been described as requiring a lot of improvement. National weed science specialists are very few in number. Weed science is handled mostly by plant protectionists who lack weed science background and many of them including counterparts in some countries cannot recognize the species as parasitic weeds (FAO, 1994).

Farmers are requiring solutions to parasitic weeds problems. They can recognize the yield losses and often mention that crops have completely been destroyed. Some farmers have abandoned planting host crops, which are most profitable and resorted to growing other less profitable ones. Most farmers are unable to recognize *Orobanche* seeds. Some believe that parasitic weeds are an act of the Devil. Some new potential techniques of controlling broomrapes by biological control and physical methods have been tested in the region with encouraging results.

Potential Application of Biological Control

Using insects and pathogens attacking *Orobanche* plants for biological control is only in a preliminary research stage (Mihajlovic, 1986; Schroeder, 1994), in spite of the fact that numerous reports were published on broomrape control using *Phytomyza orobanchiae* Kaltenbach (Diptera: Agromyzidae) which specifically feeds on *Orobanche* spp. Most of these reports originate from Europe (except Scandinavia), Mediterranean region, and eastern worlds through Arabia to Uzbekistan and possibly Afghanistan (Mihajlovic 1986; Schroeder, 1994). In 1969, 7800 ha were treated by the augmentation of *P. orobanchiae* in the USSR; and reached more than 128,000 ha in 1975 (Kovalev, 1977).

Only few examples on the use of pathogens for *Orobanche* control are recorded in the literature. The first fungus used was *Fusarium oxysporum* var. *orthoceras* in the former USSR. It remained effective for 80 days and has achieved good results on watermelon (86–100% reduction of *O. aegyptica*) but its efficacy was affected by soil temperature and humidity (Kott, 1969).

Linke et al. (1992) reported that in preliminary laboratory and field tests in Syria the fungus *Ulocladium atrum* infected and effectively destroyed underground tubercles and emerged shoots of *O. crenata*. Other efficient fungi on *Orobanche* were *Rhizoctonia solani*, *Alternaria* and *Sclerotinia* spp.

Soil Solarization

Solarization is a physical method for soil disinfestation in areas with high solar irradiation. Covering wet soil with clear polyethylene film during the summer increases soil temperature by 10 to 15°C in the upper 15 cm soil layer. This temperature increase is considered to be the main reason for various biological and physicochemical changes in the soil that affect plant growth (Katan, 1981). Crop yield increase by soil solarization was reported to be related to control of such pests as weeds, fungal pathogens, nematodes, bacteria and mites, and to higher availability of soil nutrients such as nitrogen, calcium and magnesium. A major advantage of soil solarization over other soil disinfestation techniques is that it is safe to the user and the environment.

In Iraq, soil temperatures under polyethylene mulches reached 49.7°C at 10 cm depth, compared to 33.2°C in the non-covered soil. If polyethylene foil (fine sheet) was raised 5 cm above soil surface, the temperature increased to 52.9°C (Al-Hassani et al., 1985).

In Egypt, maximum temperature in the open field of non-solarized soil, at a depth of 20 cm, was 35°C at Ismailia and Giza, while temperatures of the solarized soil were 8 and 15°C higher at Giza and Ismailia, respectively (Satour et al., 1991).

Field experiments on soil solarization conducted by ICARDA between 1985 to 1989 in northern Syria showed that the mean daily maximum temperature of uncovered soil at 5 and 10 cm depth was 38.9 and 33.8°C respectively but reached 49.5 and 44.9°C in covered soil. Soil solarization for 40 days doubled biomass production of fab. bean, lentil and field pea (Linke et al., 1991). Mean seed yield increased by 313% and straw yield by 105% (Tables 2, 3). As all the experiments except the one with pea were conducted on plots heavily infested with *Orobanche crenata*, seed yield in the non-solarized plots was low due to a high infestation with parasite. In absence of *O. crenata* infestation, seed and straw yield increase due to solarization was only 34 and 37%, respectively (Linke et al., 1991).

Table 2 Effect of solarization on seed and straw yield in kg/ha of three food legumes (modified after Linke et al., 1991)

Crop	Without solarization		With solarization	
	Seed yield	Straw yield	Seed yield	Straw yield
Faba bean	359	1601	1546	3169
Lentil	229	1493	1240	3561
Pea	645	1391	1239	2167
General mean	337	1511	1393	3102

Differences of seed and straw yields between solarized and untreated plots are significant at $P = 99.9\%$.

Table 3. Effect of solarization on *Orobanche* seed bank (number of seeds/kg soil), seed viability and the number of *Orobanche* shoots/m² (after Linke et al., 1991)

Treatment	No. of *Orobanche* seeds per kg soil	Seed viability (%) (up to 15 cm soil depth)	No. of *Orobanche* emerged shoots/m²
Control	198	86.8	60.5
Solarization	191	1.0	3.5
SE	17	1.0	11.3

The effect of solarization for six weeks was studied in naturally infested fields in the central Jordan Valley by Abu-Irmaileh (1991). The soil was prepared by tilling to form a fine-textured seed-bed starting early July each year. The field was irrigated, ploughed, levelled, then

furrowed at appropriate distances to suit the crops in the trial. Plots were irrigated prior to the solarization. After the solarization period was terminated, crops were planted with **minimal soil disturbance.** Planting holes were driven in the soil by a hand chisel or wooden stick. The hole depth was 20 cm for the transplants and 5 to 7 cm in case of direct seeding.

Abu-Irmaileh (1991) also observed that the heating effect of solarization diminishes with soil depth. Solar heating mostly affects the top soil layer, where heat-sensitive soaked weed seeds would be affected. Weed emergence following solarization is a function of weed tolerance to solar heating effect, the depth of the seeds, and the ability of the germinated seeds to emerge. Seeds of weed species that were able to germinate and emerge from deeper layers would grow in the solarized plots. Some annual weed species and *Orobanche aegyptiaca* were completely controlled by solarization. Other weed species seemed to be stimulated and emerged only in the solarized plots. This effect is probably due to germination enhancement by the warming effect of soil layers in which the seeds of the tolerant weed species were present. Soil disturbance by shallow or deep hoeing enhanced further weed emergence, but improved tomato yield. Soil covering the bare tomato stem was found to enhance the production of adventitious roots and enhanced tomato growth and yield (Abu-Irmaileh, 1991).

A plastic film for soil solarization must possess a high greenhouse effect. This effect is much higher as the transparency of the film increases the visible solar rays and short infrared (IR) band and is more opaque to the calorific radiations (long IR) (Lamberti and Basile, 1991).

The films that are defined thermic and available on the market have a transmittance below 35% with regard to long IR and higher than 82% for visible and short IR. In PVC films transmittance to long IR is less than 15% and to short IR more than 92%. Ethylenevinyl acetate (EVA) films also have a transmittance to the long IR of less than 25% and to the short IR of about 89%. However, its greenhouse effect depends on the percentage of vinyl acetate which varies between 12 and 14% in the films available on the market. The thickness of the film is also of importance.

Other films with high greenhouse effect are LDPE/EVA; it means a polyethylene (PE) with linear molecules with long and short ramification (LDPE) with ethylenevinyl acetate (EVA). Comparing two films of the same thickness—one simple layered EVA and the other LDPE/EVA (50%:50%)—the second shows an inferior greenhouse effect because the concentration of vinyl acetate is reduced by 50%.

Chemical Control

Chemical control with herbicides is carried out on limited areas (Jacobsohn and Levy, 1988; Garcia-Torres, 1994). Considerable numbers of herbicides were tested as possible control agents of broomrape, whether pre-plant, pre-emergence or post-emergence. None of those reported are known to be widely used and it is not clear whether they passed beyond the experimental stage.

The most widely tested herbicide is glyphosate which is foliar applied, 1–3 times at rates ranging from 50 to 200 g/ha. The herbicide is translocated into the roots and is taken up by the attached parasite at lethal levels. However, its phytotoxicity is a limiting factor to its use as a selective herbicide. Even in those crops where the suggested rates were selective, the margin of safety is narrow. Glyphosate was recommended for use in broad-beans in North Africa. Promising results were obtained in carrot, celery, vetch (*Vicia sativa* L.) and cabbage.

From the different means of herbicide application only preliminary trials with sublethal doses of glyphosate in eggplants have been conducted so far in the Sudan (Table 4). Glyphosate (40 g a.i./ha) sprayed 17 days after transplanting increased fruit yield of eggplants infested with *O. ramosa* above the untreated controls by 18%, while 80 and 160 g a.i./ha reduced the yields significantly. Since there is only a narrow span of beneficial effects on the parasitized crop and its possible kill this narrow

Table 4 Effects of *Orobanche ramosa* L. and application of different doses of glyphosate on yield of eggplants cv. Black beauty (Braun at al., 1984)

Treatment	Yield (kg/ha)	Compare (%) to 1.	to 2.	Number *Orobanche* plants/plot	Infestation (in %)
No *Orobanche* no gly	5361.9	-	+10.4	-	-
Orobanche no gly	4857.1	-9.4	-	26	43
Orobanche 40 g gly/ha	5752 4	+7.3	+18.4	24	42
Orobanche +80 g gly/ha	4466.7*	-16 8	-9.0	20	33
Orobanche +160 g gly/ha	4238.1*	-20.9	-12.7	19	32

span can only be achieved by applying the accurate dosage as uniformly as possible. Because of the quite insufficient application methods presently used by small-scale farmers, this control measure seems not very practicable yet, if farmers have to do it themselves. Treatments carried out by licensed applicators, however, could probably solve this problem (Braun et al., 1984).

Pronamide (Kerb) showed promising results when applied directly to the soil via irrigation to sunflowers (herbigation) (Kleifeld and Hertzlinger 1984).

Proposed Control Methods of Broomrape in Sudan

Preventive Measures

The aim of preventive methods is to avoid spreading of broomrape into new uninfested areas. This objective would be achieved by the following activities:

1. Planting clean seeds. Locally produced seeds may be cleaned by floatation (Abu-Irmaileh, 1994).

2. Prevention of moving infested soil by vehicles and farm machinery within the farm and between farms. Infested soil may be transferred with planting material. Farm machinery such as combines and containers operating on a regional basis or by contractors should be carefully cleaned.

3. Prevention of spreading broomrape seeds by farm animals by avoiding grazing. Grazing on broomrape infested fields should be prohibited (Jacobsohn, 1986). It is a common practice to allow grazing on such fields after crop harvest. Do not feed animals with contaminated hay or crop residues from infested fields. Do not allow animals to move from infested to uninfested areas.

4. Avoiding using manure from unknown sources. Use only fermented manure. Fermentation for at least 6 months assures killing parasite and other weed seeds.

5. Checking if water used for irrigation is not passing through broomrape infested fields (Jacobsohn, 1986).

6. Not moving soil, gravel, seeds or seedlings or other material from infested to clean areas (especially from infested nurseries). When collecting hay, especially of legume plants, it should be remembered

that even when flowering broomrape plants are detached from the host by pulling or cutting, the broomrape plant will produce viable seeds.

7. Avoiding broomrape seeds dispersal by erosion from infested to clean soil.

8. Creating a better awareness among farmers, agricultural technical staff, extensionists and officials who help in fostering prevention and other control methods (Babiker et al., 1994).

Cultural Control

1. Crop rotation with non host requires several years for reduction of the seed quantities in soil. This is not an effective method as seeds will remain viable in the soil for periods longer than any reasonable crop rotation. Rotation with rice reduced *Orobanche* infestation in host crops through flooding effect.

2. Flooding might serve probably in limited situations where water is available and topography might allow it.

3. Increased fertilization with nitrogenous compounds and chick manure. N fertilizer assures a good stand of crop which results in vigorous plants with less effect of the parasite.

Physical Control

1. Hand pulling, hoeing, collection and burning is an essential measure of control, but the success of this operation depends on the stage of the broomrape because considerable damage is done to the crop prior to broomrape emergence. If the operation is done when broomrape plants produce ripe fruits, the method is useless. In addition, high stand reduction could be obtained only with repeated hand pulling for more than 2-3 years (Labrada, 1994).

   When only very few broomrape plants are present in the field, hand weeding is recommended to prevent seed formation (Braun et al., 1984 and Babiker et al., 1994). It is crucial to remove the weeded *Orobanche* plants from the field and ensure their destruction even in their early flowering stage. Such plants are able to mature and produce viable seeds when left in the field (Jacobsohn, 1986).

   All collected broomrape plants should be destroyed outside the cultivated area by burning.

2. Soil solarization with or without minimum soil disturbance at planting.

In Egypt solarized plots are pre-irrigated by flooding; irrigated furrows are opened manually one day later in the sandy soils and 4–8 days later in the other soils. Plots are covered continuously using two transparent polyethylene sheets 450 cm wide and 0.05 and 0.10 mm thick containing ultra-violet absorbent (UFA). Solarization starts usually in mid-July and lasts four to seven weeks (Satour et al., 1991).

Preliminary trials in the Khartoum Province resulted in a complete control of a light to medium infestation with *O. ramosa*, a 80% reduction in the number of annual weed species and a significant decrease in the visible attack of *Moloidogyne* spp., on roots of egg plants after 30 days of covering (Braun et al., 1984). The cost of mulching material is considerable but the efficiency can be increased through repeated use on several areas during the hot season and in subsequent years. Additionally the positive side effects and the simple handling make this method especially suited for intensive vegetable production, where root nematodes also play an important role.

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Neem Leaf Powder: A Potential Source of a Soil Bio-Herbicide for *Orobanche* Control

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The plant parasite *Orobanche ramosa* L. is gaining increasing importance in Khartoum State as the major pest endangering production of solanaceous crops, particularly tomato and potato. Its steady increase in importance stems from ineffective control measures adopted by farmers. The farmers are now aware of the need for more effective control measures. Thus, the present paper reports on the outcome of trials conducted in the 1993/94 season and 1994/95 season for the control of this pest using neem seed and leaf powder in potato fields.

Materials and Methods

Season 1993/94

Potato seeds (variety Alpha) were sown on ridges 70 cm apart, inside plots measuring 3 x 6 m. Ridges were first split and potato seeds placed inside them at a spacing of 20 cm. One gram neem seed or leaf powder was mixed with the soil underneath each potato seed, then all ridges earthed up and watered. Treatments compared were as follows:

(a) neem leaf powder at 1 g/plant hole;
(b) neem seed powder at 1 g/plant hole; and
(c) control (untreated).

The design of the trial was a completely randomized block with three replicates. The criteria used for evaluation included the following:

(a) percentage of plant holes infested with *Orobanche*;
(b) average number of plants emerging in the two middle rows; and
(c) yield in kg/feddan.

Season 1994/95

To avoid the negative effects of neem powder on emergence of potato plants as happened in the previous season, 1 g neem leaf powder was placed this season as a side dressing 2, 3, 4, 5, 6 and 2 + 6 weeks after

the emergence of potato plants. Other practices were maintained as in the previous season except that neem seed powder as a treatment was omitted.

Results

Season 1993/94

Neem seed powder drastically reduced emergence of potato plants to the extent that the yield of tubers in this treatment was almost half that of the control treatment (Table 1).

Table 1 Effect of neem on emergence of potato plants and yield in kg per feddan

Treatments	Average no of plant holes in the 2 middle rows	Average no of plants emerging in the 2 middle rows	Marketable yield in kg per feddan
Control	40	38	1700
Neem seed powder	40	23	800
Neem leaf powder	40	33	1200

However, neem leaf powder, slightly affected the emergence of potato plants and reduced the yield of tubers. Counts made at different intervals from emergence of potato plants showed efficient control of *Orobanche* with neem leaf powder followed by the seed powder (Table 2).

Table 2 Effect of neem on the plant parasite *Orobanche ramosa*

Treatment	Percentage of plant holes infested			
	1st count (7 2 94)	2nd count (12.2 94)	3rd count (17 2.94)	4th count (23 2.94)
Control	3 3	13 0	21 0	30 0
Neem seed powder	1.3	9 0	13 0	26.0
Neem leaf powder	1.0	6 0	12 0	21 0

Season 1994/95

Modifying the application of neem leaf powder in this season to be placed as side dressing did not interfere with emergenee of potato plants; furthermore, it resulted in adequate control of *Orobanche ramosa* (Table 3). The application of neem at the 6th week after emergence of potato plants showed the best control of *Orobanche*. However, all treatments produced comparable yields of tubers.

Table 3. The effect of *Orobanche* control with neem at different intervals from plants emergence

Treatment after emergence	Plant population after emergence	No of *Orobanche* infested plant holes per plot	Yield in kg/plot
2 weeks	24	6.3 bcd	0.4 a
3 weeks	23	10 7 ab	1.0 a
4 weeks	25	5.3 cd	0 8 a
6 weeks	23	7.0 abc	0.8 a
6 weeks	21	2 3 d	0.8 a
2 + 6 weeks	25	4 0 cd	1.2 a
Control	26	11.0 a	1.0 a
SE		SE ± 1.48	SE ± 0.14

Discussion and Conclusion

Direct contact of neem powder with potato seeds in the first season, resulted in the failure of a sizeable number of potato seeds to emerge, particularly when neem seed powder was applied. This could be from physiological toxicity of neem powder. On the other hand, neem-treated plots produced lower yields compared to the control, particularly those treated with neem seed powder. This could be attributed to the low plant populations in these plots compared to the control treatment.

Neem leaf powder effectively reduced infestation with *Orobanche* especially if applied at 2 and 6 weeks after potato emergence. Neem was reported by some research workers in the USA that it retards the production of exudates from the roots of sorghum plants which stimulate the seeds of *Striga hermontheca* to germinate. Since *Orobanche* is a plant parasite like *Striga* and has the same habit of feeding from the host plant, a similar retardation of root exudates could have occurred by the application of neem leading to the reduction of *Orobanche* infestation in neem-treated plots.

In the second season, the application of neem as side dressing resulted in normal emergence. Our results also showed that the application of neem leaf powder at 6 weeks from the emergence of potato plants was the best timing for the application. But in spite of the adequate control of *Orobanche* in neem-treated plots, their yield was similar to the control plots. This could be attributed to the application of an overdose of 1 g leaf powder per plant hole resulting in physiological toxicity. However, in the next season's trial, the correct dose of neem leaf powder that controls *Orobanche* effectively and does not affect the yield of potato would be identified.

The Role of IPM Farmer Field Schools in Facing New Problems in Vegetable Production

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The main objective of the Farmer Field Schools is to help farmers to become experts in their field. The FAO/ARC IPM Project in cooperation with the Extension Department of the Gezira State Ministry of Agriculture started organizing FFSs in the State in 1993 to equip farmers with knowledge, practices and positive attitudes for doing their jobs better as well as to enable them to become effective communicators and depend on themselves in making sound decisions to face their challenges. Regular training of FFS members (farmers) during weekly field sessions is considered the backbone of the FFSs. During these sessions farmers are trained on the IPM main elements in accordance to their needs and interest.

The *Orobanche* broomrape (halouk) problem was noticed by farmers participating in the FFS in the Fadasi area in January 1995. The IPM trainers found out that the problem started in 1988 in a small area and now covers a large area and the parasitic weed severely attacks tomato crop costing farmers a great loss of their expected income.

The IPM project undertook the following actions:

1. Prof. Abdalla Hamdoun, the weed scientist of the Agricultural Research Corporation, Gezira Research Station has been contacted and invited to participate in the FFS meeting on *Orobanche*.

2. Preparation of the TV programme on broomrape distribution, damage and general advice to farmers on how to reduce losses by halouk infestation.

3. Interviewing some farmers in the most affected area. Some farmers have already developed their own cultural practices to reduce losses such as: selection of good seeds (Mr Abdelal), proper fertilization and irrigation.

4. Publishing the interview with farmers in the IPM Newsletter No. 2 April, 1995.

5. Publishing an additional article on halouk in the IPM Newsletter No. 4, June 1995 on different aspects of the problem to orient farmers and field officers on the seriousness of broomrape (halouk) as a pest. The emphasis was that the problem should be handled collectively by the farming community, the field extensionists and the plant protectionists.

6. A handout was prepared in Arabic in June 1995 giving a description of halouk, host plants, means of multiplication and how to control it through cultural, mechanical and chemical techniques.

Mr N. Khairi has been granted fellowship from the FAO/IPM Project to pursue his higher education (M.Sc.) on validation of some cultural practices controlling Orobanche.

Participatory Approach in Validating Selected Control Methods of *Orobanche* in Fadasi Area, Central Sudan

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Broomrapes, halouk (*Orobanche*) and dodders (*Cuscuta*) were reported in the 1940s as localized agricultural pests in Sudan. *Orobanche ramosa* L. and *Cuscuta campestris* Yunck were the most important species. An outbreak of the parasites was observed in the 1980s with the highest infestation in the Nile Valley and associated with intensified agriculture.

During field visits to the vegetable growing areas located along the Blue Nile, farmers of Fadasi village requested the FAO/ARC IPM Project to establish a Farmer Field School because their winter crops were being damaged by unknown factors. Later, regular field interactions with farmers have disclosed that the tomato crops were severely infested by halouk. Records of the Agricultural Research Station showed that small isolated plots in Fadasi Elamarab location were infested by *Orobanche* in 1988. Since then, the parasitic weed has spread to surrounding fields and now covers almost the whole area in Fadasi.

In the 1994/95 winter season, a number of fields with winter tomato have showed a heavy infestation and yield reduction to approx. 40–80%. The participatory interactions with vegetable farmers through the IPM Farmer Field School (FFS) indicated that the farmers affected were not aware of *Orobanche* biology, the mode of its spread and preventive control method. Extension training of farmers was immediately initiated through regular weekly field discussions in the IPM FFS as well as through TV and radio presentations (see Alsaffar and Nasr Eldin Khairi in these proceedings).

The impact of training has been later evaluated by interviewing 24 randomly selected vegetable farmers from the affected areas in Fadasi village. 91.7% of interviewed farmers in Fadasi area confirmed that the halouk has already infested their fields. All respondents (including 8 3% whose fields were free from *Orobanche*) are familiar with and know how the broomrape (halouk) plants look like. However, only 42% could describe the colour of its flowers. 92% believe that the broomrape produces its own roots.

Only 8% of the farmers were aware that the halouk plant takes nutrients from host vegetable plant, 4% from soil and 87.5% could not

describe from where the parasitic halouk takes nutrients indicating farmers' awareness of the problem but the lack of knowledge on the nature of its parasitic feeding.

For some farmers the *Orobanche* could be a new pest as shown by the farmers' response to the next question — When did you see halouk on your field for the first time? 37.5% of respondents have identified the first occurrence of halouk on their vegetable field only last growing season (Table 1). Half of the interviewed farmers observed the appearance of halouk during the last ten years and 8.4% more than 10 years ago. Only 4.2% of farmers have not yet confirmed the appearance of *Orobanche* on their fields.

Fifty percent of Fadasi farmers have first noticed halouk on their own farms and 45.8% on the neighbour's field. 37.5% farmers confirmed that the infested neighbour's field was located in a close vicinity (less than 50 m) to his field when he observed *Orobanche* for the first time. 4.2% farmers' field was located between 50 – 100 m or 100 –1000 m from the infested field in the previous years indicating a direct threat from an adjacent infested field to a new field. The first respondents' (37.5%) confrontation with *Orobanche* appearance was already on heavily infested fields. 62.5% farmers observed only slightly infested fields for the first time.

Table 1. Appearance of *Orobanche* on vegetable fields in Fadasi area noticed for the first time by farmers on their own fields

Time	No. of farmers	Frequency (in %)
The 1994/95 season	9	37.5
Between 1 – 5 years ago	6	25.1
Between 5 – 10 years ago	6	25.1
More than 10 years ago	2	8.4
Not yet noticed	1	4.2

Most of the interviewed farmers observed that *Orobanche* reduced crop productivity (83.3% farmers) and 16.7% stated that the halouk caused plant death after first fruiting.

95.9% of farmers acknowledged carrying out some control methods: 91.7% were pulling off and weeding halouk and 4.2% have implemented a rotation to reduce damage. 66.7% of farmers tried to pull off halouk plants before flowering and 29.2% during flowering or at later stages. 83.3% were aware thet there is a specific critical period recommended for removing the halouk plants and 70.8% knew that pulling off should be done before flowering. Exactly the same percentage of farmers confirmed that their neighbours were also pulling off the halouk plants

from their crop. 16.7% of farmers noticed that their neighbours did not carry out any control method.

Most of the vegetable fields in Fadasi area do not have fences made of thorny acacia branches or wires. 87.5% of farmers allow free movement of domestic animals (sheep, goats, cows) betwe'n fields and only 4.2% have tried to restrict the grazing on their fields.

The pereeption of the halouk damage on tomato crop varies between farmers. Nearly half of the respondents indicated approx. 75% yield reduction (Table 2). The time of tomato planting by 35.8% Fadasi farmers coincides with later *Orobanche* appearance during the winter growing season (Table 3). However, the tomato plants planted in November on seed beds will be transplanted in December. It is known that transplanted tomato plants suffer less from the *Orobanche* infestation than directly seeded plants.

Interviewed Fadasi farmers are growing a wide range of crops (Table 4) but they only recorded occurrence of halouk on tomato (100% of farmers); carrot (4.2%) and Jew's mallow (4.5% farmers).

In summary — the Fadasi farmers are well aware of the destructive effect of *Orobanche* on their tomato crop but they do not relate the severity of the halouk damage with the season. The market price of tomato dictates the planting time of their tomato crop.

Table 2. Perception of yield reduction of tomato crop infested by *Orobanche* by vegetable farmers in Fadasi area

Estimated yield reduction of tomato crop (in %)	Respondents	Frequency (in %)
To 10	6	25.0
10–25	3	12.6
26–50	4	16.7
51–75	10	41.7
75–100	1	4.2

Table 3. Planting time of tomato in Fadasi area infested by *Orobanche*

Time	Respondents	Frequency (in %)
February	2	4 2
April	2	4 2
June	4	8.4
August	3	6.3
October	4	8 4
November	11	22.9
December	6	12 9
Depending on season (no strict preference)	16	33.3

Table 4 List of crops grown by the Fadasi farmers (in %) and *Orobanche* occurrence on various crops as perceived by farmers		
Crop	Cultivation (in %)	*Orobanche* occurrence (in %)
Tomato	100	100
Eggplant	20.8	-
Sweet pepper	29.2	-
Hot pepper	50.0	-
Potato	4.2	-
Okra	29.2	-
French bean	12.5	-
Broad-bean	20.8	-
Chickpea	4.2	-
Groundnut	8.3	-
Alfalfa	8.3	-
Snake cucumber	33.3	-
Squash	8.3	-
Musk melon	8.3	-
Water melon	25.0	-
Onion	58.3	-
Garlic	8.3	-
Carrot	50.0	4.2
Purslane	16.7	-
Garden rocket	12.5	-
Jew's mallow	25.0	4.2

The farmers were able to describe the halouk plants but more training is needed to explain the parasitic nature of halouk feeding on crop plant roots and the ways of distribution of halouk seeds between fields. Other methods than pulling off halouk plants are unknown to the farmers.

More emphasis should also be given for involving the Fadasi farmer community in restricting *Orobanche* seed distribution between fields by domestic animals. In some other villages in the vicinity of Fadasi, the vegetable farmers are already building fences from acacia branches around their fields, which should restrict free movement of goats and sheep (see Dabrowski and Hamdoun, in this proceedings).

The planned field experiments for the 1995/96 growing season on various options of controlling the halouk will also provide opportunities for further interactions with vegetable farmers in the Fadasi area.

Participatory Research on *Orobanche* Control

Realizing the increasing threat of the *Orobanche* to vegetable production by small-scale farmers, the FAO/ARC IPM Project has initiated participatory research with farmers of the Farmer Field School located in the Fadasi village to validate some selected control methods recommended for the region.

The following activities are undertaken in the 1995/96 season by involving selected farmers in demonstrating various options of broomrape control and establishing the following experiments:

- (i) Effectiveness and economic evaluation of regular hand-pulling of *Orobanche* plants (farmers' acceptance, labour cost, effectiveness, effect on yield);
- (ii) Effect of three levels of N,P,K on *Orobanche* and tomato crop (comparison of germination of *Orobanche* plants, growth pattern of the weed and tomato crops, effect on yield);
- (iii) Effect of delaying planting of tomato (infestation level by *Orobanche*, yield; economic impact of delaying);
- (iv) Comparison of *Orobanche* infestation on direct seeded plants versus 4 week transplanted plants;
- (v) Effect of soil solarization by using transparent polyethylene sheets (6 weeks) (economic analysis).
- (vi) The *Orobanche* developmental rate (biomass production) on selected weeds will be compared to the parasite performance on tomatoes and eggplants, the most commonly affected vegetables in central Sudan.

The following weed species will be included in the field observations:

- (i) Common thornapple, sakran — *Datura stramonium* L.; gubbein, muda — *Solanum dubium* Fresen and black night shade, einab al diib — *Solanum nigrum* L. (Family: Solanaceae);
- (ii) Croton, tarba, taroob — *Chrozophora plicata* (Vahl.) A. Juss. ex Spreng. (Family: Euphoroiaceae);
- (iii) Jew's mallow, khudra, molukhia — *Corchorus olitorius* L. (Family: Tiliaceae);
- (iv) Um galagil — *Aristolochia bracteolata* Lam. (Family: Aristolochiaceae); and
- (v) Cheese-weed, mallow, khubbaizeh — *Malva parniflora* L. (Family: Malvaceae).

In addition to the research projects, the FAO/ARC IPM Project will carry out the following additional activities:

(i) Training of the farmer community in Fadasi on *Orobanche* biology, mode of movement between fields and villages and control methods. The training will be organized under the existing IPM FFS in Fadasi and involve local extensionists;

(ii) Developing of extension materials in Arabic emphasizing a community approach in the implementation of control methods of *Orobanche*.

Research on *Orobanche* at the University of Gezira

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Orobanche is a root-parasite which causes severe damage to many crops in Sudan. *Orobanche ramosa* is the species present in central Sudan and attacks mainly tomatoes, eggplants and potatoes. High level infestation by this parasite was noticed in Wad Medani area (e.g. Fadasi) and 3–6 shoots of this parasite were observed to attack one single tomato plant. *Orobanche* produces an enormous number of minute seeds that could be disseminated by wind, irrigation water, animals and agricultural machinery. Although *Orobanche* was first noticed in Khartoum during the 1950s; rapid southward spread along the Blue Nile bank was noticed. In addition it was also noticed to invade heavy clay soils in the Gezira scheme. In Khartoum province *Orobanche* was claimed to attack host plants other than solanaceous crops. The present situation of this parasite could be illustrated in the following points:

1. A parasite highly damaging to vegetable crops causing significant yield losses and menace to stop their successful cultivation.

2. Steadily spreading southward along the Blue Nile river (silty soil) and started to spread in heavy clay soils of the Gezira scheme.

3. Apparently able to expand its host plants.

4. Taking into consideration these points, research programmes were elaborated at the University of Gezira to combat this "disaster".

Initiation of *Orobanche* Research

Realizing the importance of vegetable crops grown in the small private farms spreading along the Blue Nile bank, it was suggested that some effort should be made to improve production and productivity in this region. A preliminary survey was made during 1988 in which various problems, including pests, diseases, cultural methods were recorded. One of the problems discussed in the report was the potential hazard presented by *Orobanche* in tomato. No further effort has followed this survey. However, in 1993, a new research project initiated at the University

of Gezira, seriously reconsidered the problem and a work programme was elaborated by scientists of the UG and ARC.

On-Going Research Within the UG-ARC-INRA Project

This programme was started in 1994 in collaboration with scientists from UG, ARC and University of Nantes, France. Miss Duria Mubarak was registered for Ph.D. at the University of Gezira and later another M.Sc. student was recruited to collaborate in certain control aspects. The Ph.D. programme entitled: Study on the biology, ecology and control of *Orobanche* in solanaceous vegetables in Sudan, has considered the following aspects:

1. Biology

1.1. Identification of the various species present in the area.

1.2. Study of the variability of *O. ramosa* to elucidate its apparent ability to attack different host plants (species, varieties) within the family Solanaceae and among other families. This comprises molecular and biological studies.

1.3. Host plant association (host-parasite relationships and host specificity).

2. Ecology

2.1. Seed load of infested soils — methodology was already established.

2.2. Vertical distribution of *Orobanche* seeds in the soil. Sampling at various depths.

2.3. Effect of various soil types in the establishment of the parasite.

3. Physiology

3.1. Study of germination stimulants; natural from tomato and other host root or artificial stimulants, e.g. GR_{24}.

3.2. Study of germination inhibitors.

3.3. Manipulation of certain chemicals present in the parasite that enhance severity of symptoms on parasitized hosts, e.g. mannitol,

4. Control

4.1. As the parasite is rapidly and steadily spreading, it is highly recommended to start with measures to stop this spread. Most important is the pulling and burning of *Orobanche* shoots before flower setting.

4.2. Formulation of IPM plan. This is a medium to long-term research objective which should be started anyway.

The various components of this IPM programme are the following:

A Cultural Methods

1. Removal of *Orobanche* shoot immediately after emergence above soil level.

2. Manipulation of planting depth. It was noticed that the site of attachment to tomato roots was restricted to the first 10 cm of the soil on the roots growing horizontally to soil. Planting deeper in the soil may reduce the attack.

3. Evaluation of bio-control agents, e.g. *Fusarium* sp. and insects.

B Chemical Methods

1. Evaluation of herbicides to inhibit germination and/or to stop attachment of haustoria on host roots.

2. Use of neem extract; mainly a neem leaf powder.

C Resistant Varieties (Tomato)

1. Search of sources of resistance within wild tomato species, e.g. *Lycopersicon cheesmani, L. hirsutum, L. pimpinellifolium, L. peruvianum* and *L. chilense.*

2. Testing progenies of crosses made with these species and *L. esculentum.*

3. Screening of commercial tomato cultivars and lines. Many newly generated varieties which have got a wide genetic background as genes for resistance to many diseases have recently been incorporated in these cultivars.

Conclusions

The *Orobanche* problem has become a real menace to successful cultivation of tomato and other solanaceous crops in the Gezira and Khartoum provinces. Efforts should be directed towards upgrading our knowledge on the various biological, ecological and physiological aspects of this parasite. Meanwhile research on sound and cheap control techniques should be initiated. This calls for long collaborative efforts of pathologists, botanists, breeders and agronomists, to work together within the framework of a well-defined project to face this problem.

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